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Form Approved  
OMB NO. 0704-0188

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1. AGENCY USE ONLY (Leave Blank)		2. REPORT DATE April 28, 2003	3. REPORT TYPE AND DATES COVERED Final Report. 8/1/2002 -1/31/2003
4. TITLE AND SUBTITLE STIR - Synthesis and Characterization of Nanotube-Elastomer Damping Composites		5. FUNDING NUMBERS Grant No. DAAD19-02-1-0326 Proposal No. 43858-EG-II	
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9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) U. S. Army Research Office P.O. Box 12211 Research Triangle Park, NC 27709-2211		10. SPONSORING / MONITORING AGENCY REPORT NUMBER  43858.1-EG-11	
11. SUPPLEMENTARY NOTES The views, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy or decision, unless so designated by other documentation.			
12 a. DISTRIBUTION / AVAILABILITY STATEMENT  Approved for public release; distribution unlimited.		12 b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) The objectives of this research are (a) to develop novel polymeric damping composites through distributing carbon nanotubes (CNTs) within the host polymer, and (b) to investigate the damping characteristics of such new composites. We aim to obtain good understanding and insight of this innovative approach and provide guidelines for future research possibilities. In this study, the system is modeled using a four-phase composite, composed of a resin, voids, and bonded and debonded nanotubes. To address damping effects, the concept of interfacial "stick-slip" frictional motion between the nanotubes and the resin is proposed. The analytical results show that the critical bonding stress, nanotube weight ratio and structure deformation are the factors affecting the damping characteristic. Experimental efforts are also performed to verify the trends predicted by the analysis. Through comparing with neat resin specimens, the study shows that one can indeed enhance damping by adding CNT fillers into polymeric resins. The test results also show that the damping ratio of specimens with nanotubes depends on the strain (deformation) of the composite, with trends similar to those predicted by the analytical model, showing the validity of the model and the analytical predictions.			
14. SUBJECT TERMS Carbon nanotubes; damping; polymeric composites		15. NUMBER OF PAGES Seven (including this page)	
		16. PRICE CODE	
17. SECURITY CLASSIFICATION OR REPORT UNCLASSIFIED	18. SECURITY CLASSIFICATION ON THIS PAGE UNCLASSIFIED	19. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED	20. LIMITATION OF ABSTRACT  UL

NSN 7540-01-280-5500

Standard Form 298 (Rev.2-89)  
Prescribed by ANSI Std. Z39-18  
298-102

# **STIR - Synthesis and Characterization of Nanotube-Elastomer Damping Composites**

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**Proposal No. 43858-EG-II  
Grant No. DAAD19-02-1-0326**

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## STATEMENT OF THE PROBLEM STUDIED

The objectives of this research are (a) to develop novel polymeric damping composites through distributing carbon nanotubes (CNTs) within the host polymer, and (b) to investigate the damping characteristics of such new composites. We aim to obtain good understanding and insight of this innovative approach and provide guidelines for future research possibilities.

## SUMMARY OF THE MOST IMPORTANT RESULTS

The major achievements are described in the following paragraphs.

### (1) Modeling and analytical efforts for damping characterization of CNT-based composites

The objective of this sub-task aims at the development of a constitutive model to describe the mechanism of energy dissipation for polymeric composites distributed with single-walled carbon nanotubes.

Because of their ultra small, nanometer scale size and low density, the surface area to mass ratio (specific area) of carbon nanotubes is extremely large. Therefore, in a nanotube-based polymeric composite structure, it is anticipated that high damping can be achieved by taking advantage of the interfacial friction between the nanotubes and the polymer resins. In addition, the CNT's large aspect ratio and high elastic modulus features allow for the design of such composites with large differences in strain between the constituents, which could further enhance the interfacial energy dissipation ability. Most of the investigations to date on carbon nanotube-based composites have focused on their electrical properties, strength, and modulus. Despite their wonderful engineering potential, the damping properties of CNT-based composites have not been examined in any detail.

To address nanometer-scale load transfer behavior at the interfaces between the nanotubes and polymer, the atomic level “stick-slip” model is used to describe the load transfer behavior between the nanotube and the matrix, as well as the characteristics of strain-dependent energy dissipation. The friction law is characterized by a critical shear stress, which is a

macromechanical characterization of molecular interactions. This critical value separates material systems into two different regions: an energy-conservative region for perfect bonding, and an energy-dissipative region due to incremental sliding of nanotubes. Through utilizing the developed model, parametric study results are obtained (Figure 1). It is observed that with small deformation (strain), damping increases with increasing strain. This is due to the growing area of debonded interface in this strain range. After reaching a maximum value, the damping loss factor decreases because most of the additional input energy at higher applied strain is being stored in the matrix instead of being dissipated at the interface. Therefore, it is concluded that maximum damping effects can be obtained within a certain strain range. It is also shown that maximum damping effects, indicated by the peak values of loss factor in Figure 1, increase with the magnitude of critical bonding stress and nanotube volume ratio. Since the choice of polymeric matrix material, nanotube surface treatment, and composite manufacturing process can have significant effects on the critical bonding stress, the possibility exists for achieving optimal structural damping performance through the design of different nanotube-based composites.

## (2) Composite fabrication and experimental efforts

The objective of this sub-task is to develop carbon nanotube epoxy composites, experimentally evaluate damping characteristics of the composites, and verify the analytical predictions. Composite specimens are prepared with the nanotube weight ratio ranging from 0.5% to 3%. An ultrasonic agitation procedure is applied to enhance the nanotube dispersion and surfactant is added to improve bonding between the nanotubes and the matrix material. Figure 2 shows scanning electron microscope photos of fracture surfaces of the composites. The fine light colored lines are so-called “ropes” of nanotubes consisting of parallel arrays of up to several dozen individual nanotubes in cross-section. Damping characteristics of the specimens are experimentally investigated utilizing a cantilever composite beam specimen. An impulse is applied at the free end of the cantilever beam and a transient response is measured using an accelerometer. The logarithmic decrement method is used to derive the specimen damping ratio value. By examining the test data from specimens with (Figure 3b) and without (Figure 3a) nanotubes, it is clear that adding nanotubes enhances the damping characteristics of the composite structure significantly. It is also illustrated that the damping ratio of specimens with

nanotubes depends on the strain (deformation) of the composite, with trends similar to those predicted by the analytical model (Figure 3b), showing the validity of the model and the analytical predictions.

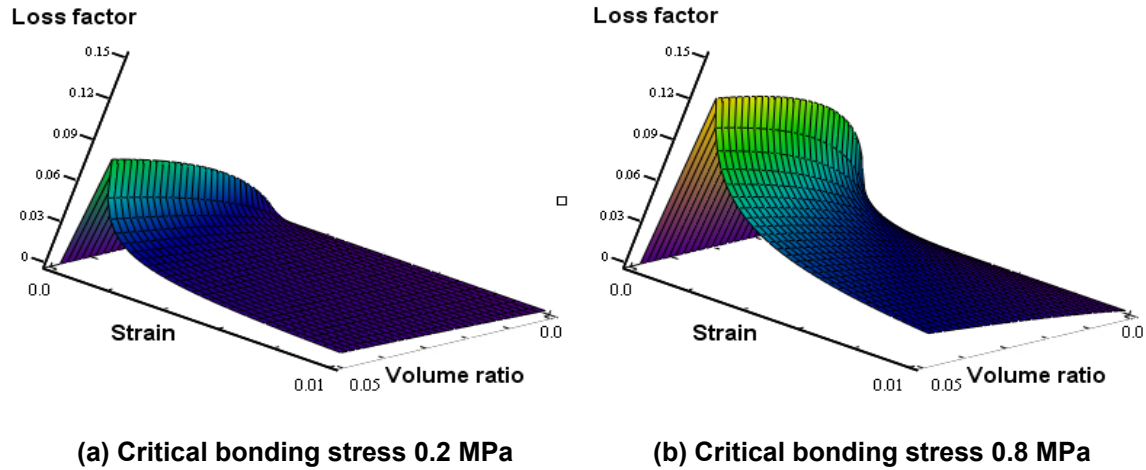


Figure 1. Loss factors with change in volume ratio, strain and bond strength.

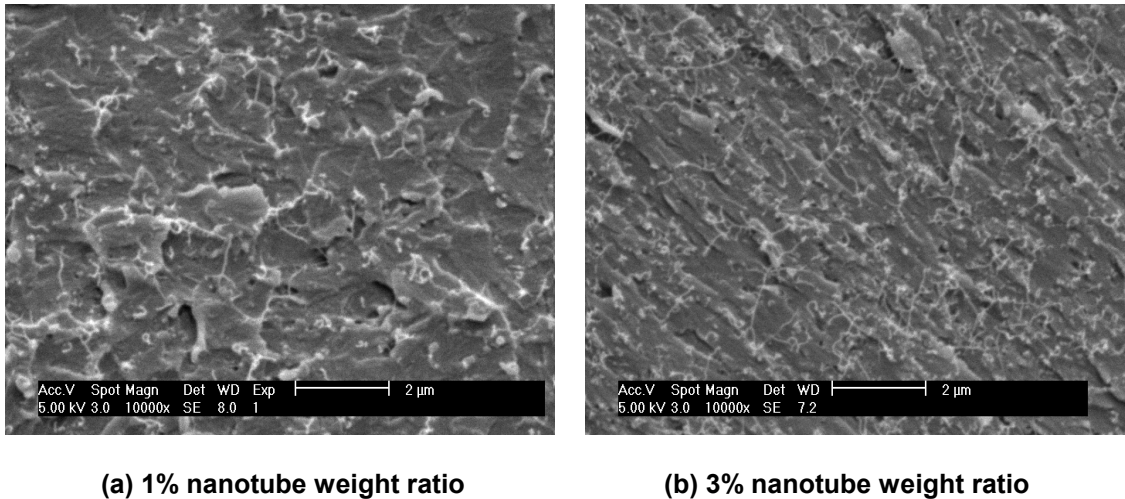


Figure 2. SEM photos of fractured epoxy/carbon nanotube composites

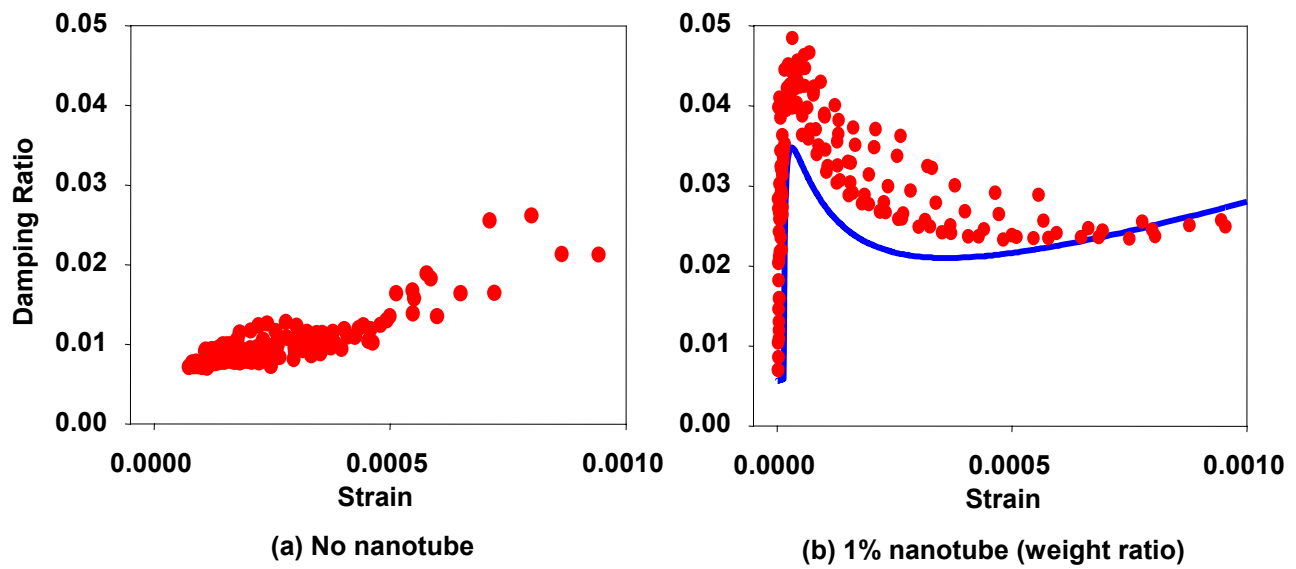


Figure 3. Comparison of damping ( • :Test results. — :Analytical results)

## LIST OF PUBLICATIONS

X. Zhou, E. Shin, K. W. Wang, and C. Bakis, “Damping Characteristics of Nanotube Enhanced Composites,” *ASME Design Engineering Technical Conference*, DETC2003/VIB-48537, Chicago, IL, 2003.

## PARTICIPANTS AND DEGREES AWARDED

Personnel supported: K. W. Wang (PI), Charles Bakis (Co-PI), Eungsoo Shin (Postdoc Researcher).